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THE JUAN DE FUCA LOBE OF THE CORDILLERAN ICE SHEET

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There were two large glaciers in western Washington during the latest, or Vashon, glaciation of that region. Each was essentially an elongated lobe of the great piedmont glacier which accumulated between the mountains of Vancouver Island and the British Columbia mainland. One lobe moved southward into the Puget Sound depression, filling it completely and pushing over into the Chehalis Valley to the south. The other moved westward through the Juan de Fuca Valley, extending as a tidewater glacier into the open waters of the Pacific Ocean. Though both of these lobes were augmented to some extent by valley glaciers from mountains in Washington, neither were true piedmont glaciers of these mountains.

Ice from this piedmont glacier in the depression now occupied by Georgia Strait moved almost directly south over the San Juan Islands, striating and grooving rock surfaces from tide-level virtually to the summit of the highest peak of the islands, 2,400 feet A.T.

In Fuca Strait south of the islands, the ice divided into two parts, one continuing southward as the Puget Sound Glacier, the other being deflected to the west and north of west as the Juan de Fuca Glacier. The Puget Sound Glacier pushed as far south as latitude $46^{\circ} 50' N.$, about 80 miles south of the re-entrant angle between the two lobes. Its extra-morainic outwash extended down the Chehalis Valley to the head of Grays Harbor, 30 miles beyond the limits of the ice.¹

The Juan de Fuca Glacier extended westward along the southern coast of Vancouver Island nearly to Cape Beale² and spread

¹ J. H. Bretz, "Glaciation of the Puget Sound Region," *Washington Geological Survey, Bulletin 8* (1913).

² C. H. Clapp, "Southern Vancouver Island." *Canada Geological Survey, Memoir 13* (1912), p. 144.

out as a broad spatula over the low-lying northwest salient of the Olympic Peninsula south of the strait. It reached westward nearly or quite to longitude 125° W., 10 or 12 miles off the Washington coast beyond Cape Flattery.

There is a narrow foreland between the Olympic Mountains and Juan de Fuca Strait, composed largely of Pleistocene materials. It is separated from the coastal plain west of the mountains by a group of ridges which strike parallel to the shore of the strait. They extend from Crescent Lake to the extremity of the Olympic Peninsula. They are everywhere several hundred feet high and certain summits are mapped as high as 4,000 feet. They serve as a divide between Soleduck River on the south and the short streams tributary to the Strait on the north.

The foreland terrace north of these ridges gradually narrows westward until it disappears, while the valley on the south side, between the ridges and the main mass of the Olympics, broadens and joins the coastal plain facing the Pacific.

The slopes of these ridges bear little or no glacial drift but the valleys between them contain deposits of Vashon till. The till of the foreland and in these valleys is, in general, light in color and contains plentiful granitic material, very much like the Vashon till of Puget Sound. Many erratics are of identical material. It seems clear that the *débris* was brought from the same feeding grounds north of the international boundary line.

But west of Crescent Lake and south of these ridges, the drift contains a large amount of basalt and dark-colored sandstone and conglomeratic *débris* which came from the Olympics immediately to the south, and which is not found in the till north of the ridges.

The eastern portion of these ridges apparently served as an imperfect barrier in the Juan de Fuca Glacier between drift from the distant Georgia Strait and from the nearby Olympics. Farther west, however, the ridges were overridden by the northern ice which carried its granitic drift southward almost to the mouth of Quil-layute River.

The coastal plain of the Olympic Peninsula is densely forested. There are few roads and clearings. Such as do exist are along the streams. These conditions have forbidden any attempt to trace a

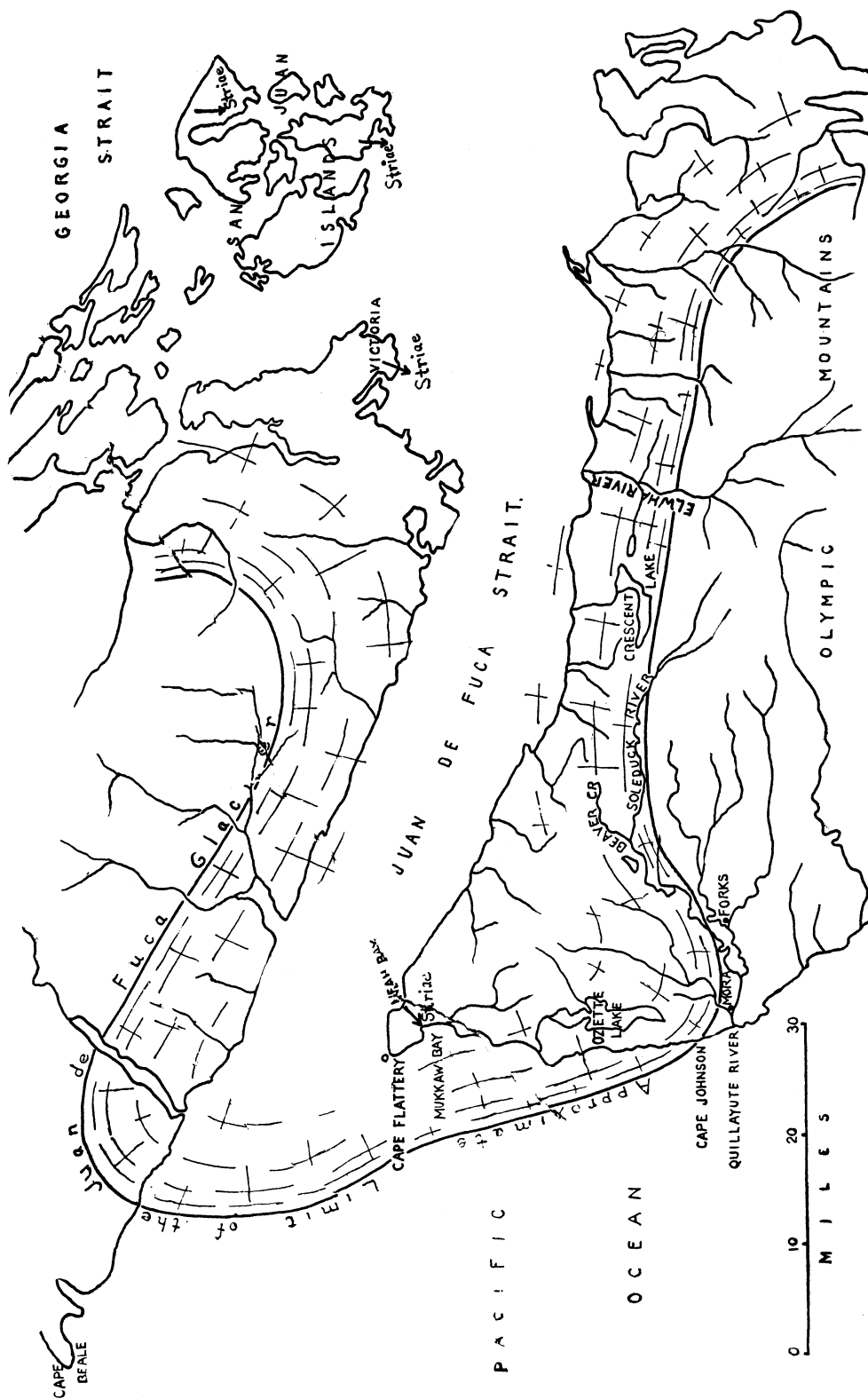


FIG. 1.—Approximate outline of the Juan de Fuca Glacier at its maximum

terminal moraine, and the limits of the Juan de Fuca Glacier as shown in Figure 1 are only approximate.

Glacial till is exposed at the junction of Beaver Creek and Soleduck River, near Pleasant Lake. It is dark gray in color, and contains some finely striated and faceted pebbles. Several granite pebbles, like those in the typical drift of Puget Sound, were found here.

Many boulders, some of them finely striated, are scattered along the road from Pleasant Lake to Forks, and from Forks almost to Mora at the mouth of Quillayute River.

Granite boulders with a maximum diameter of 5 feet lie in coves between rocky headlands along the beach immediately north of the mouth of Quillayute River. Their situation and their size render it highly improbable that they traveled along the beach for any considerable distance. The occurrence of granite boulders here, and between Forks and Mora, indicates that the Juan de Fuca Glacier probably pushed south of the latitude of Cape Johnson.

Two miles north of Cape Johnson there is a sea cliff of glacial till, 25 feet high. The till is light colored and has many pebbles of the same kinds of rock which give Puget Sound drift some of its conspicuous pebbles. The fresh gray color and the shallow oxidized zone above it indicate the Vashon age of the deposit. It is material derived unquestionably from the feeding grounds of the great piedmont glacier whose bifurcation formed both the Puget Sound and Juan de Fuca lobes. Material from the Olympics is either lacking or a negligible quantity. The deposit apparently lies in a pre-Vashon valley whose northern portion contains Ozette Lake.

Between this place and Cape Flattery, at the extreme northwestern tip of the Olympic Peninsula, there are several such sections of till in the sea cliffs. There are also exposures of outwash gravel derived from the same source. The Juan de Fuca Glacier, composed of ice from Georgia Strait, clearly pushed out beyond the present coast. On Vancouver Island it reached at least 15 miles farther west than the longitude of Cape Flattery. Valley trains indicate that the sea stood 30 feet or so above tide at the time of this glaciation. The Juan de Fuca Glacier therefore must have possessed

a tidewater front from a point east of Cape Beale on Vancouver Island to Cape Johnson on the Olympic Peninsula, a distance of about 60 miles. Only Greenland and Antarctica today possess tidewater glaciers of comparable extent. Figure 1 shows the proportions of this lobe and the probable greater deployment at the mouth of the strait, along which the greatest movement of ice doubtless occurred.

The wastage of the Juan de Fuca Glacier was largely by bergs, notably in contrast with that of the glacier of Puget Sound which terminated at its maximum wholly on a land surface. Only the southern margin of the Juan de Fuca Glacier terminated on the land, and only in such a situation could outwash deposits be made at the maximum extent of the ice.

The area invaded by the southern portion of the Juan de Fuca Glacier is drained by Quillayute River. This stream and its tributaries on the coastal plain flow through young valleys cut some 50 feet into a great valley train which extends from Forks to the ocean. At Mora, the altitude of the surface of the valley train is about 30 feet above tide.

At Forks Prairie on the valley train, the gravel is more than 100 feet deep, and wells drilled here have encountered many large boulders distributed throughout the gravel. Quillayute Prairie, between Forks and Mora, is an isolated plateau-like portion, a few square miles in area and from 75 to 135 feet above the surface of the surrounding plain. It is composed of gravel but has an irregular surface in its northeastern part, strongly suggestive of the presence of blocks of ice during its building. Its isolated position apparently is the result of dissection of an earlier valley train of which it is a portion. From the evidence of the irregular topography in the northeastern portion, the terminal margin of Juan de Fuca Glacier is here mapped as reaching Quillayute Prairie.

A valley train extends down the Soleduck Valley from the base of the Olympic Mountains and joins this broader tract beyond the limits reached by the glacier. The gravel of which it is composed is dark in color, and was derived largely from basaltic rocks and dark-colored sedimentaries. This is typical of most of the debris from this portion of the Olympic Mountains. But scattered

through it are numerous light-colored granitic pebbles and cobbles, which were brought by the Juan de Fuca Glacier over the divide between the Straits and Soleduck River. The Soleduck Valley train was built after the front of the ice had withdrawn eastward to a position somewhere near Lake Crescent. Indeed, aggradation from Olympic débris alone may have continued long after the Juan de Fuca Glacier had retreated entirely from the Soleduck drainage.

The thickness of the Juan de Fuca Glacier was sufficient to enable it to cross the divide between the Straits and the Soleduck valleys. The British Admiralty chart shows summits in this range 4,000 feet high, but the crest in general can hardly average 2,000 feet. Enough of the range was overridden to allow a continuous glacier to spread out on the coastal plain to the south, as shown in preceding paragraphs. Better figures on the thickness of the glacier are to be obtained from features of the Elwha Valley, a few miles east of Crescent Lake.

No granite is known *in situ* in the Olympic Mountains. "Float granite" however occurs in the lower portions of several Olympic valleys draining to Puget Sound and Fuca Strait, and very probably has been derived from Cordilleran ice which pushed up on the flanks and back into the valleys of both the eastern and northern sides of the Olympics.

The river gravel of the Elwha Valley contains scattered granitic boulders and cobbles at least as far up as Elkhorn Ranger Station, 15 to 20 miles by valley from the Strait. Granitic erratics are abundant along the trail some hundreds of feet above the valley bottom at least 15 miles south of the Strait.

No lobe of ice from the northern glacier could have pushed this far up the narrow Elwha Valley from the lowland occupied by the Juan de Fuca Glacier, and if these boulders record the presence of ice originally from Georgia Strait, the thickness of the Juan de Fuca Glacier must have exceeded the height of the ridges it had to cross. Hurricane Hills, the highest ridge directly in the path of such invading northern ice, attains an altitude throughout its length of 5,000 feet. Juan de Fuca Strait to the north is 600 feet deep. The Juan de Fuca Glacier opposite the mouth of the Elwha Valley therefore must have been more than a mile thick. This is

70 miles back from the front of the glacier, and indicates an average gradient of its surface of at least 80 feet per mile for that distance. It is probable that the front, which terminated in the open Pacific, was cliffed, and that this gradient must be reduced accordingly.

Based on similar evidence, the surface gradient of the Puget Sound Glacier averaged at least 47 feet per mile for 50 miles back from its front. In both cases, these are but minimum values for the thickness and gradient.

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